Published in final edited form as:
Psychol Aging. 2003 March ; 18(1): 54–67.

Age-Related Changes in Selective Attention and Perceptual Load During Visual Search

David J. Madden and **Linda K. Langley**
Center for the Study of Aging and Human Development and Department of Psychiatry and Behavioral Sciences, Duke University Medical Center.

Abstract

Three visual search experiments were conducted to test the hypothesis that age differences in selective attention vary as a function of perceptual load (E. A. Maylor & N. Lavie, 1998). Under resource-limited conditions (Experiments 1 and 2), the distraction from irrelevant display items generally decreased as display size (perceptual load) increased. This perceptual load effect was similar for younger and older adults, contrary to the findings of Maylor and Lavie. Distraction at low perceptual loads appeared to reflect both general and specific inhibitory mechanisms. Under more data-limited conditions (Experiment 3), an age-related decline in selective attention was evident, but the age difference was not attributable to capacity limitations as predicted by the perceptual load theory.

An age-related decline is frequently evident in the overall efficiency of visual search performance, but the selective allocation of attention to task-relevant information, expressed as changes in performance associated with target-location and target-identity cues, is in many respects constant as a function of age (Hartley, 1992; Madden & Plude, 1993; McDowd & Shaw, 2000). Selection performance on nonsearch measures of attention, including Stroop, negative-priming, and response compatibility tasks, has exhibited variability in age-related patterns of stability and decline as a function of specific task demands. Investigations of response compatibility effects, for example, have found that the increase in reaction time (RT) associated with response-incompatible flankers is greater for older adults than for younger adults (Zeef & Kok, 1993; Zeef, Sonke, Kok, Buiten, & Kenemans, 1996), but the reverse pattern has also been reported (Cerella, 1985; Madden & Gottlob, 1997; Wright & Elias, 1979), as have age constancies (Hahn & Kramer, 1995; Kramer, Humphrey, Larish, Logan, & Strayer, 1994; Sullivan, 1999).

Maylor and Lavie (1998) suggested that the perceptual load of the task is an important variable contributing to the observed pattern of age differences in visual selective attention performance. A basic premise of the perceptual load theory (Lavie, 1995;Lavie & Tsal, 1994) is that a clear physical distinction between relevant and irrelevant information is not alone sufficient to prevent the processing of irrelevant information. For processing to be selective, it is also necessary that the perceptual load of the task be sufficiently high to either approach or exceed the upper limit of available attentional resources. The theory assumes that task performance is limited by attentional resources, conceptualized as “an internal input, essential for processing but available in limited quantities, that can be shared within or between tasks” (Lavie & Tsal, 1994, p. 184). It is also assumed that in a perceptual task, the observer

---

Correspondence concerning this article should be addressed to David J. Madden, Box 2980, Duke University Medical Center, Durham, North Carolina 27710. E-mail: djm@geri.duke.edu.

This work was supported by Grants R37 AG02163 and R01 AG11622 from the National Institute on Aging. We are grateful to Susanne M. Harris, Laura L. Denny, Elizabeth Race, and Andrea Guess for technical assistance and to Elizabeth Maylor and Art Kramer for helpful comments on the manuscript.

cannot allocate less than the total capacity available, and processing continues automatically until capacity limits are reached. As a result, the allocation of selective attention is successful in excluding irrelevant information only when the processing demands of relevant information approach the limits of available capacity.

Lavie (1995) provided empirical support for the perceptual load theory in three experiments that measured choice RT for a target letter accompanied by a flanker letter. The effectiveness of selective attention was defined in terms of the magnitude of performance disruption from the response-incompatible flanker (B. A. Eriksen & C. W. Eriksen, 1974;C. W. Eriksen, 1995). Lavie found that several variables representing increased perceptual load (e.g., number of display items, conjunction search vs. feature search) were associated with an increase in the effectiveness of selective attention to the target (expressed as a decrease in the magnitude of the response compatibility effect). Lavie and Cox (1997) demonstrated that the ability to ignore distractors was more successful under conditions of inefficient target search (target among similar nontargets) than under conditions of efficient target search (target among dissimilar nontargets). In the perceptual load theory, the rejection of distractors at higher perceptual loads is a passive process that occurs simply as the result of cognitive resources being fully engaged by the task-relevant activities, whereas distractor rejection at lower perceptual loads involves a more active inhibitory component (Lavie & Fox, 2000). Neuroimaging studies have demonstrated that these changes in selective attention as a function of perceptual load reflect the functioning of specific brain regions mediating visual processing (Handy & Mangun, 2000;Rees, Frith, & Lavie, 1997).

Maylor and Lavie (1998) have proposed that changes in age differences in measures of selective attention can be accounted for within the perceptual load theory. Those authors used a two-choice version of visual search in which perceptual load of relevant processing was manipulated by varying the number of letters in a circular display (display sizes of one, two, four, or six letters). Participants were instructed to ignore a distractor letter presented outside (to the left or to the right of) the circular display, which was either incompatible with the target (the letter assigned to the other response) or neutral (a letter not assigned to a response). Consistent with perceptual load theory, the disruption of visual search associated with response-incompatible distractors, relative to neutral distractors, decreased as the number of items in the display (perceptual load) increased. This perceptual load effect was more pronounced for older adults than for younger adults: The distraction from the response-incompatible letter was greater for older adults than for younger adults at the lowest level of perceptual load (a display size of one letter) and diminished more rapidly for older adults with increasing load. Maylor and Lavie characterized their findings in terms of two related explanatory constructs. The first is an age-related decline in inhibitory control, which limits the efficiency of selective attention, for older adults, at lower perceptual loads (Hasher, Zacks, & May, 1999;Kane, Hasher, Stoltzfus, Zacks, & Connelly, 1994; but cf. Burke, 1997;Kramer et al., 1994). The second explanatory construct is an age-related reduction in processing capacity (Anderson, 1999;Craik & Byrd, 1982), which leads to a greater improvement in attentional selectivity, as a function of increasing perceptual load, for older adults than for younger adults.

The Maylor and Lavie (1998) application of perceptual load theory to age-related changes in selective attention is important in several respects. The theory provides separate empirical measures relating to selective attention (the magnitude of RT response compatibility effects) and attentional capacity (the change in response compatibility effects as a function of increasing perceptual load), within a theoretical model of the interaction of these attentional processes. The variable pattern of age effects observed in some selective attention tasks described previously (e.g., Hahn & Kramer, 1995;Zeef & Kok, 1993) may consequently be related to variations in the perceptual load of the tasks. In addition, the perceptual load theory provides empirical predictions that can be distinguished from alternative accounts such as generalized slowing (Madden, 2001;Salthouse, 1996). In the Maylor and Lavie theory, age differences in the RT pattern representing selective attention (i.e., response compatibility effects) will be most pronounced at lower perceptual loads. Generalized slowing, in contrast, would predict that age differences in task performance would be more clearly evident in the task conditions leading to the slower responses, in this case higher perceptual loads.

In three experiments, we tested the generality and replicability of Maylor and Lavie's (1998) findings of age differences in distraction as a function of perceptual load. In particular, we were concerned with the relatively high error rates reported by Maylor and Lavie. The older adults' error rate ranged from .20 to .25 for Maylor and Lavie's six-letter displays, which is relatively high for an investigation of RT. The task-related changes in error rate were in accord with the RT changes, and Maylor and Lavie reported that the RT effects were comparable for subgroups of participants with different accuracy levels. Nevertheless, the high error rates suggest that participants may have been operating closer to data-limited conditions (i.e., near an identification threshold) than to resourcelimited (above-threshold) conditions, at least for the six-letter displays. When error rates are high, the interpretation of RT can be problematic, even if speed-accuracy trade-offs are not apparent (Santee & Egeth, 1982). We thus wanted to replicate the Maylor and Lavie findings for RT under conditions of higher overall accuracy, which are more representative of resource-limited investigations of adult age differences in RT. In an attempt to keep error rates comparably low between the age groups, we increased display duration beyond the 100-ms value used by Maylor and Lavie. We either allowed the display to remain on the screen until a response was made (Experiment 1) or limited display duration to a different value for each group (Experiment 2), so that accuracy remained relatively high and similar between the groups.

We were also interested in the potential role of a single distractor presented outside the display in the perceptual load effects observed in Maylor and Lavie (1998). This type of distractor can be considered an *onset singleton*, which has been shown to be particularly difficult to ignore (Bacon & Egeth, 1994;Theeuwes & Burger, 1998). There is evidence that attentional capture by onset singletons is greater for older adults than for younger adults (Juola, Koshino, Warner, McMickell, & Peterson, 2000;Pratt & Bellomo, 1999), and this aspect of the display may have played a central role in the observed age differences in distraction at low perceptual loads. We thus integrated the distractor into the structure of the display. We included two instances of the same distractor at the 3- and 9-o'clock positions of the circular display and instructed participants to ignore items at these positions.

Finally, we investigated whether the distraction effects reported by Maylor and Lavie (1998) were related specifically to response selection or involved other processes such as internal recognition responses (C. W. Eriksen & Schultz, 1979). We used incompatible and neutral trials, as did Maylor and Lavie, but in addition we included compatible trials on which the distractors were not identical to the target but shared the same response. In nonsearch tasks that maintain a constant location for the target, response-incompatible flankers reliably increase RT across a variety of manipulations of display presentation (B. A. Eriksen & C. W. Eriksen, 1974;C. W. Eriksen, 1995). The effects of response-compatible flankers are less consistent and may lead to response facilitation when the flankers are presented before the target (Flowers, 1990;Taylor, 1977). But when response-compatible flankers occur simultaneously with the target, there is often some form of disruption of performance, apparently because attention is not sufficiently selective to eliminate all of the competition among internal recognition responses (C. W. Eriksen & Schultz, 1979;Grice & Gwynne, 1985;Proctor & Fober, 1985).

Lavie (1995) and Lavie and Cox (1997), in studies of younger adults, found that when the distractor was identical to the target, the associated magnitude of distraction was variable, presumably because (unlike response-incompatible distractors) the disruptive influence of target-identical distractors was combined with priming from visual feature similarity. We consequently used, in addition to response-incompatible and neutral distractors, trials on which the distractor was response compatible but not identical to the target. Thus, if the inhibitory mechanism described by Maylor and Lavie (1998) is associated specifically with reducing the interference from the priming of incompatible responses, then distraction should be evident only for incompatible trials and not for compatible trials. A more general inhibitory mechanism, however, reflecting competition between internal recognition responses to potential targets, as distinct from the selection of a specific response, would lead to a measurable distraction effect for both compatible and incompatible trials, relative to neutral trials.

To summarize, we tested whether age differences in the interaction between selective attention and perceptual load would persist under resource-limited (high accuracy) and non-singleton distractor conditions. We added the compatible condition to clarify whether the distraction effects are specific to response selection or are instead related to a more general inhibitory mechanism.

Experiment 1

In Experiment 1, younger and older adults performed a two-choice version of visual search in which they searched a circular display for a target letter. Four target letters were used, with two targets assigned to each of the response keys. Participants pressed a key according to which one target occurred in a display. Distractor letters were located within the circular display at the 3- and 9-o'clock positions. We manipulated perceptual load by varying the number of relevant nontarget letters in the display (one, three, or five nontargets). For each display size, there were three types of trials: incompatible, compatible, and neutral. The distractor letter in the incompatible trials was a letter assigned to the opposite response of the target letter. The letter used as the distractor in compatible trials was the letter assigned to the same response as the target letter. The distractor letter for neutral trials was a letter assigned to neither response.

The data of primary interest were the changes in the compatibility effects as a function of display size. We assessed these effects by comparing RTs on both incompatible trials and compatible trials with RTs on neutral trials. On the basis of perceptual load theory, we predicted that the absolute magnitude of RT changes associated with the observed compatibility effects would decrease as a function of increasing display size. In terms of age differences, we predicted that distracting information would be processed automatically by both age groups at lower perceptual loads (i.e., the small display sizes) but that because of age-related changes in inhibitory control, compatibility effects would be greater for older adults than for younger adults. An inhibitory mechanism related specifically to response selection would be evident as a restriction of the distraction effects to the incompatible trials, whereas a more general mechanism would yield distraction effects on both compatible and incompatible trials. We also anticipated that as perceptual load increased, the magnitude of the response compatibility effects would decrease at a faster rate for older adults than for younger adults because of age-related reductions in processing capacity.

Method

Participants—Twenty-four younger adults between 18 and 24 years of age and 24 older adults between 60 and 81 years of age participated in Experiment 1. There were 12 women in each age group. Participant characteristics (e.g., education, acuity, and psychometric performance) are presented in Table 1. Younger participants were Duke University students, and older participants were community-dwelling adults recruited through the Duke Aging Center Subject Registry. All participants possessed at least a high school (12-year) education. Participants completed the Vocabulary subtest of the Wechsler Adult Intelligence Scale—

Revised (WAIS-R; Wechsler, 1981) and a computerized version of the WAIS-R Digit-Symbol Substitution subtest, which measures RT as well as accuracy to individual items (Salthouse, 1992). Corrected near visual acuity, as measured binocularly with a Keystone Telebinocular vision tester with splitring slides (Mast/Keystone, Davenport, IA), was at least 20/40 for each participant.

Apparatus and stimuli—A Gateway 2000 P5-120 microcomputer (Gateway 2000, N. Sioux City, SD) with a 120-MHz Pentium processor controlled presentation of stimuli and measurement of responses. Stimuli were presented on a Gateway 2000 Vivitron 17-in. (327 mm × 240 mm display area) high-resolution color video monitor, with a 70-Hz refresh rate. Participants responded by pressing one of two buttons on a five-button PST Serial Response Box, Model 200A (Psychology Software Tools, Pittsburgh, PA). The response box, connected to the serial port of the computer, was positioned on the table directly in front of participants. Desk lamps and subdued overhead lights (ceiling-mounted fluorescent lights shielded by plastic covers) provided lower than normal room illumination to reduce glare on the computer monitor. A chin rest maintained participants' viewing distance from the computer monitor at 48 cm.

The experimental task was created and run using Micro Experimental Laboratory (MEL; Schneider, 1988). The stimuli were white characters presented against a black background. Letter stimuli were created in an uppercase sans serif font subtending a visual angle of 1.13° vertically and 0.76° horizontally. The letters were arranged around the perimeter of an imaginary circle with a diameter of 7.95°. Although the letter size was approximately double that used by Maylor and Lavie (1998), the display diameter was also approximately doubled, yielding a retinal image size comparable to that in the earlier study. Each trial display contained two distractor letters; one target letter; and one, three, or five nontarget letters. This resulted in relevant display sizes (excluding the distractor letters) of two, four, or six letters (Display Sizes 2, 4, and 6, respectively). Sample displays are presented in Figure 1. The two distractor letters were positioned in the circle at 3 and 9 o'clock. In Display Size 2, the target letter was positioned at 12 or 6 o'clock, and the nontarget letter was positioned at the remaining of those two locations. For Display Sizes 4 and 6, the target letter could be presented at any of the six nondistractor locations. In Display Size 4, the two empty positions were always directly opposite one another (at 1:30 and 7:30 or 4:30 and 10:30). In Display Size 6, all eight positions contained letters. With all eight display positions occupied, the distance between adjacent letters was approximately 0.9°-1.55°, depending on letter shape.

The four target letters were *H, C, S,* and *K*. The letters *H* and *C* were assigned to one response key, and the letters *S* and *K* were assigned to the other. Thus, one relatively angular and one relatively curved letter was assigned to each response. Assignment of targets to keys was counterbalanced across participants. The two distractors of a trial always shared the same letter identity, which was determined by the compatibility condition. The three conditions were compatible, incompatible, and neutral, so named to describe the letter identity relationship between the target and distractors. For compatible trials, the distractors' letter identity was the letter assigned to the same response as the target letter (e.g., if the target letter was *H*, then the distractor letter was *C*). For incompatible trials, the distractors' letter identity was one of the two letters associated with the other response (e.g., if the target letter was *H*, then the distractor letter was *S* or *K*). Neutral trials contained a distractor letter other than the four letters associated with a key press response (the letter *R*). The possible identities of the remaining letters in the display, the nontarget letters, were *B, D, F, G, J, L, N, Q, P, T, X,* and *Y*. Thus, the relevant nontarget set contained six relatively angular letters and six relatively curved letters.

There were 432 trials in total, 144 trials at each display size (two, four, and six relevant items). Within each display size, there were 48 trials for each compatibility condition. Within these

48 trials, the target appeared eight times at each of the six relevant display locations. The test trials were presented as eight blocks of 54 trials, balanced for compatibility condition, display size, target letter identity, target display position, and nontarget letter identity. The order in which the eight blocks of trials were presented varied across participants. Participants were assigned to one of eight unique block orders, which balanced the position of a particular block within the sequence.

Procedure—Participants performed the task in one session lasting approximately 1 hr. The experimenter explained the task to participants with the assistance of drawn examples of the display configurations. Participants were told that one of four target letters would appear on every trial in one of six positions of a circular display. When an *H* or *C* was presented, they should press one key, and when an *S* or *K* was presented, they should press the other key. They were told to ignore the letters in the 3- and 9-o'clock positions, even if one of the four target letters was presented there, because those letters were included only to make the task more difficult. They were told to keep their eyes focused in the center of the circle. Participants were encouraged to perform the task quickly while maintaining high accuracy. Participants rested their index fingers on the outer left and right keys of the button box throughout the task.

A trial sequence proceeded as follows. A fixation point (an asterisk) appeared in the center of the screen for 500 ms. At the offset of the fixation point, the stimulus display appeared and remained on the screen until the participant responded or 10 s had elapsed. Reaction time was measured from the onset of the circular display. An accuracy indicator appeared on the screen informing participants whether they had responded correctly (a green +), had responded incorrectly (a red *X*), or had failed to respond (a yellow *?*). The accuracy indicator was displayed for 800 to 1,200 ms, with an average time of 1,000 ms over a block of trials. The presentation time of the accuracy indicator was varied to reduce anticipatory responses based on a learned rhythm of trial presentation. The warning signal for the next trial appeared at the offset of the accuracy indicator.

Participants performed three practice blocks of 18 trials. After the practice blocks, participants completed eight test blocks of 54 trials. A screen was presented at the beginning of each block reminding participants of the task instructions and target-button assignments. Participants were allowed to rest between blocks of trials; they pressed the middle key of the response box when they were ready to proceed with a block. A summary screen at the end of a block indicated the total number of correct, incorrect, and incomplete trials.

The display remained on the screen until a response was made, allowing sufficient time for participants to shift their gaze. Eye movements were consequently monitored with a video camera to ensure that participants maintained visual fixation throughout a trial. Trials on which an eye movement was made were not discarded or replaced, but participants who shifted their eyes from fixation on more than 10% of the trials were replaced. One older adult was excluded because of excessive eye movements and replaced by one of the participants described in the *Participants* section.

Results

Reaction time—Individual trials on which RT was either less than 150 ms or more than 5,000 ms were categorized as outliers, which eliminated less than 1% of trials for each age group. The mean percentage of trials with eye movements was 1.5% for younger adults and 2.1% for older adults.

The means of median RTs for correct responses are presented in Table 2. A 2 × 3 × 3 mixed analysis of variance (ANOVA) on median RTs was conducted with age group (younger adults and older adults) as the between-subjects variable and compatibility condition (incompatible,

compatible, and neutral trials) and relevant display size (two, four, and six items) as the within-subjects variables. Bonferroni *t* tests with alpha $p = .05$ were used for all post hoc pairwise comparisons. All three of the main effects were significant: age group, $F(1, 46) = 31.5$, $p < .01$; compatibility condition, $F(2, 92) = 26.7$, $p < .01$; and display size, $F(2, 92) = 200.4$, $p < .01$. Older adults were 401 ms slower than were younger adults. The compatible RTs were significantly higher than neutral RTs (by 44 ms), and the incompatible RTs were in turn significantly higher than the compatible RTs (by 31 ms). Meansearch RT increased by 229 ms from Display Size 2 to Display Size 4 and by 161 ms from Display Size 4 to Display Size 6. Display size interacted with both compatibility condition, $F(4, 184) = 7.3$, $p < .01$, and age group, $F(2, 92) = 13.8$, $p < .01$. Contrary to predictions, there were no interactions between age group and compatibility condition.

To explore the Compatibility × Display Size interaction, we examined compatibility effects at each display size, averaged across age group. The compatibility effect at Display Size 2, $F(2, 94) = 28.9$, $p < .01$, was characterized by greater RTs in the incompatible condition (1,100 ms) and in the compatible condition (1,100 ms) than in the neutral condition (1,018 ms). A similar pattern was observed at Display Size 4, $F(2, 94) = 19.6$, $p < .01$, except that there was an additional slowing for responses on incompatible trials (1,367 ms) relative to compatible trials (1,306 ms), which were in turn slower than responses on neutral trials (1,241 ms). The compatibility effects at Display Size 6, however, were not significant.

We conducted additional analyses of the Compatibility × Display Size interaction, in terms of the changes in the RT difference scores representing compatibility effects, as a function of display size (Figure 2). The incompatible-neutral effect varied as a function of display size, $F(2, 94) = 8.1$, $p < .01$, and was significantly greater than zero at both Display Size 2 (82 ms) and Display Size 4 (126 ms), but these values did not differ from each other. At Display Size 6 the 17-ms distraction effect for the incompatible trials did not differ significantly from zero. The compatible-neutral effect also varied with display size in a similar manner, $F(2, 94) = 10.2$, $p < .01$. There were comparable distraction effects for compatible trials at Display Size 2 (92 ms) and Display Size 4 (65 ms), both effects were significantly greater than zero. At Display Size 6 there was a 28-ms facilitation in RT for compatible trials (i.e., neutral RT was higher than compatible RT), which did not differ significantly from zero.

To characterize the nature of the group differences in RT as a function of display size (Age Group × Display Size interaction), RT regression slopes were calculated for each participant, representing the rate of search (i.e., processing time per item) through the display. The search functions relating RT to display size were well described by linear regressions (mean $r^2 = .93$ for both younger adults and older adults), and the older adults' slopes (123 ms per item) were significantly steeper than those of the younger adults (72 ms per item), $F(1, 46) = 18.7$, $p < .01$.

Errors—Overall, response failures were rare. Both younger adults and older adults failed to respond within the allotted time (10 s) on less than 1% of trials. Error rates for incorrect responses (Table 2) were also low (2.4% for younger adults, 2.1% for older adults). Because both groups performed with a minimal number of errors that did not vary systematically with either display size or compatibility condition, we did not analyze the error data further.

Discussion

Experiment 1 demonstrated that the interaction of selective attention and perceptual load remained detectable in the context of relatively resource-limited (long-duration) displays and accompanying low error rates. Response compatibility effects for RT decreased as display size increased, consistent with a perceptual load interpretation that selective attention was implemented only when processing demands exceeded available capacity. Distractors associated with a target response disrupted visual search performance at the smaller display sizes (two and four relevant items) but not at the largest display size (six relevant items). The finding that distractor effects were maintained until the relevant display size exceeded four items is consistent with previous findings (Lavie & Cox, 1997; Lavie & Fox, 2000; Yantis & Jones, 1991) and suggests that this is a boundary condition for capacity limitations. When attention is directed to four or fewer items, irrelevant as well as relevant stimuli are processed.

For both age groups, RT increased in a relatively linear manner as a function of increasing display size, suggesting an inefficient search through the display items (Wolfe, 1998). The RT slopes were steeper for older adults than for younger adults, consistent with previous results indicating an age-related decline in the efficiency of search under resource-limited conditions (Madden, Pierce, & Allen, 1996; Plude & Hoyer, 1986). In contrast to the findings of Maylor and Lavie (1998), however, there were no age differences in either the magnitude of response compatibility effects or the rate of decline of these effects with increasing display size. Search times for both age groups were disrupted significantly by distracting information at the smaller perceptual loads but not at the largest perceptual load, suggesting that younger adults and older adults implemented selective attention in a similar manner as perceptual load increased. This pattern is consistent with previous findings of age constancy in response compatibility effects (Hahn & Kramer, 1995; Kramer et al., 1994; Sullivan, 1999).

In addition, for both age groups, search at Display Sizes 2 and 4 was disrupted by both response-compatible and -incompatible distractors, relative to neutral distractors. Thus, the distraction from the irrelevant display items was not due entirely to the priming of incompatible responses but also involved a more general form of distraction. Related findings in nonsearch tasks have been attributed to competition among internal recognition responses (C. W. Eriksen & Schultz, 1979; Grice & Gwynne, 1985; Proctor & Fober, 1985). In the present search task, it is likely that this competition arises from the fact that the location of the target is not predictable. Search thus requires shifting an attentional focus across the display (C. W. Eriksen & Yeh, 1985; Madden, 1992). When the currently attended display character activates a response, the response must be inhibited until the display location of the activation can be determined, to ensure that the decision is not based on evidence from one of the distractors. Interestingly, at Display Size 4 there was a specific effect of response competition above and beyond the more general inhibitory mechanism, as reflected in the significant increase in incompatible RT relative to compatible RT (cf. Taylor, 1977). There was no evidence of age-related change, however, in either the general or specific forms of inhibition observed in Experiment 1.

Experiment 2

The design of Experiment 1 differed from that of Maylor and Lavie (1998) in several respects, and it is therefore difficult to determine which variable or variables accounted for the discrepancies between studies in reported age effects. It is possible that the incorporation of the distractor within the display eliminated age differences in distraction due to differential susceptibilities to onset singletons. Or it may be that age differences in distraction were eliminated because of the resource-limited (and high-accuracy) conditions of the present experiment. On this latter point, there is evidence that age differences in distractor effects are more prominent as display duration is decreased (Harpur, Scialfa, & Thomas, 1995;Scialfa & Harpur, 1994). Thus, we shortened the display duration in Experiment 2 with the expectation that such displays might be more likely to reveal the pattern of age differences in distraction reported by Maylor and Lavie.

Because we wanted to maintain error rates at a relatively low level for both younger adults and older adults, we conducted pilot testing and found that optimal display durations for this task were 250 ms for younger adults and 750 ms for older adults. These durations kept error rates at approximately 5% in each group. We predicted that if the detection of age-related changes in the interaction between perceptual load and selective attention required limited display durations, then the pattern of results observed by Maylor and Lavie (1998) should be evident in this experiment.

Method

Participants—Participants were 32 younger adults between 18 and 29 years of age and 32 older adults between 60 and 81 years of age (Table 1). There were 16 women in each age group. Participants were recruited in the same manner as in Experiment 1, but none had participated in the previous experiment.

Apparatus and stimuli—The apparatus and stimuli were the same as those used in Experiment 1.

Procedure—The procedure was the same as that of Experiment 1, except that the display was presented on the screen for a limited duration that varied for younger and older adults. After the fixation point, the display screen for younger adults was presented for 250 ms, followed by a blank screen for 2,250 ms. For older adults, the display screen was presented for 750 ms, followed by a blank screen for 1,750 ms. Participants could respond while viewing either the display screen or the blank screen; therefore, the total time to respond (display plus blank screen time) was the same for younger and older adults (2,500 ms).

As in Experiment 1, participants performed three practice blocks of 18 trials, but display duration varied across the three blocks. During the firstpractice block, the display remained on the screen for 1,000 ms to allow participants ample time to view the display. The display durations for the second and third practice blocks were shortened to 500 and 250 ms for younger adults and to 850 and 750 ms for older adults. Thus, by the third practice block, each age group was performing the task with the display duration to be used during the test blocks. The blank-screen time across the practice blocks remained at 2,250 ms for younger adults and 1,750 ms for older adults, the same times used during the test blocks.

Experiment 1 demonstrated that participants were able to maintain fixation in this task, and thus eye movements were not monitored. Although saccades were possible, particularly with the 750-ms displays, participants were instructed that in the long run, maintaining fixation would maximize accuracy.

Results

Reaction time—The mean of median RTs for correct responses are presented in Table 3. There were only two individual trials (one within each age group) on which the RT was less than 150 ms, and these two trials were eliminated as outliers.

Median RTs were submitted to a 2 × 3 × 3 mixed ANOVA identical to that used in Experiment 1. All three of the main effects were significant: age group, $F(1, 62) = 21.7$, $p < .01$; compatibility condition, $F(2, 124) = 26.3$, $p < .01$; and display size, $F(2, 124) = 343.9$, $p < .01$. Older adults were 180 ms slower than were younger adults. Incompatible RTs were significantly higher than compatible RTs (by 23 ms), which in turn were significantly higher than neutral RTs (by 25 ms). Search RTs increased by 132 ms from Display Size 2 to Display Size 4 and by 85 ms from Display Size 4 to Display Size 6. Display size interacted with both compatibility condition, $F(4, 248) = 14.5$, $p < .01$, and age group, $F(2, 124) = 4.8$, $p < .01$. Contrary to predictions, there were no interactions between age group and compatibility condition.

To explore the Compatibility × Display Size interaction, we examined compatibility effects at each display size, averaged across age group. The compatibility effect was significant at Display Size 2, $F(2, 126) = 52.5$, $p < .01$, and was characterized by comparable RTs in the incompatible (948 ms) and compatible (942 ms) conditions, both of which were significantly higher than in the neutral condition (876 ms). A similar pattern was found at Display Size 4, $F(2, 126) = 18.6$, $p < .01$, except that there was an additional slowing for responses on incompatible trials (1,090 ms) relative to compatible trials (1,054 ms), which were in turn slower than responses on neutral trials (1,018 ms). In contrast, at Display Size 6, $F(2, 126) = 3.9$, $p < .05$, the paired comparisons indicated that neutral RTs (1,147 ms) did not differ from either incompatible RTs (1,148 ms) or compatible RTs (1,121 ms) but that the latter two types of trials differed, with incompatible RTs greater than compatible RTs.

Changes in the RT difference scores representing the compatibility effects, as a function of display size, are presented in Figure 3. The incompatible-neutral effect diminished significantly across display size, $F(2, 126) = 15.7$, $p < .01$, being significantly larger at both Display Size 2 (72 ms) and Display Size 4 (72 ms) than at Display Size 6 (1 ms). The compatible-neutral effect demonstrated the same pattern, $F(2, 126) = 27.0$, $p < .01$, with mean values of 65 ms at Display Size 2 and 36 ms at Display Size 4. The compatible trials were in addition associated with a 27-ms benefit effect (i.e., neutral RT higher than compatible RT) for Display Size 6. This latter effect, however, was not significantly different from zero.

To explore the Age Group × Display Size interaction, slopes for the function relating RT to display size were calculated for each participant. As in Experiment 1, these functions were highly linear, with mean $r^2 = .95$ for younger adults and .91 for older adults. The mean slope value was significantly higher for older adults (60 ms per item) than for younger adults (48 ms per item), $F(1, 62) = 5.9$, $p < .05$.

Errors—The mean percentage of trials on which participants failed to respond was low for both younger adults (0.5%) and older adults (1.6%). Error rates for incorrect responses are presented in Table 3. Because the error rates were somewhat higher than those in Experiment 1 (5.3% for younger adults, 6.4% for older adults), we examined them by ANOVA, using the same independent variables as in the RT analysis. There were main effects of compatibility, $F(2, 124) = 12.4$, $p < .01$, and display size, $F(2, 124) = 121.6$, $p < .01$. Error rates were higher in the incompatible condition (6.6%) and in the compatible condition (5.9%) than in the neutral condition (5.0%). Error rates for Display Size 6 (9.5%) were higher than those for Display Size 4 (5.7%), which in turn were higher than those for Display Size 2 (2.3%). Compatibility effects interacted with both age group, $F(2, 124) = 3.6$, $p < .05$, and display size, $F(4, 248) = 3.8$, $p < .01$.

In further analyses of the Age Group × Compatibility interaction, we examined the compatibility effect within each age group. The compatibility conditions varied significantly for younger adults, $F(2, 62) = 10.2$, $p < .01$, and the younger adults' error rates were greater in the incompatible condition (6.4%) than in either the compatible (5.0%) or neutral (4.5%) conditions. There was also a compatibility effect for older adults, $F(2, 62) = 6.0$, $p < .01$, and their error rates were greater in both the incompatible (6.7%) and compatible (7.0%) conditions than in the neutral condition (5.5%). Considering each compatibility condition separately, the 2% age-related increase in error rate for the compatible condition was significant, $F(1, 62) = 7.5$, $p < .01$, whereas the age difference was not significant in either of the other conditions.

To explore the Compatibility × Display Size interaction, we examined compatibility effects at each display size, averaged across age group. The compatibility effect was significant at Display Size 2, $F(2, 126) = 4.2$, $p < .05$, and at Display Size 4, $F(2, 126) = 15.2$, $p < .01$, but not at Display Size 6. Pairwise comparisons indicated that at Display Size 2, the only significant difference was between the compatible (2.8%) and neutral (1.8%) conditions, whereas at Display Size 4, error rate in both the incompatible (7.1%) and compatible (6.1%) conditions was higher than in the neutral condition (4.0%).

Discussion

As in Experiment 1, RT compatibility effects decreased as a function of increasing perceptual load (display size). Therefore, limiting the duration of the display, although keeping the error rate relatively low, did not eliminate the interaction between perceptual load and selective attention. Also consistent with the results of Experiment 1 was the evidence for the combined influence of both general and specific forms of distraction. At the lower levels of perceptual load (Display Sizes 2 and 4), RT for both compatible and incompatible trials was significantly higher than RT for neutral trials, reflecting a general form of distraction from targetrelevant information. Similar to the pattern observed in Experiment 1, Display Size 4 was associated with an additional, specific influence of response competition, as reflected in the further increase in RT for incompatible trials relative to compatible trials. These findings yield the new information that the inhibitory mechanism described by Maylor and Lavie (1998) comprises both general and response-specific components, but the reason that the response-level component would be most clearly evident at Display Size 4 is not apparent.

In both Experiments 1 and 2, there was no significant distraction from either incompatible or compatible distractors, relative to neutral distractors, at Display Size 6, but in both experiments there was a hint of a facilitation effect for compatible trials. At Display Size 6, compatible RT was lower than neutral RT by 28 ms in Experiment 1 and by 27 ms in Experiment 2. Neither of these specific effects was significant, but there was a significant overall compatibility effect in Experiment 2. This type of performance benefit can be viewed as an automatic process when the facilitation occurs without an accompanying RT cost for incompatible trials (Posner & Snyder, 1975). An automatic facilitation from compatible distractors would be consistent with the perceptual load theory, which assumes that distractor processing at higher perceptual loads does not involve an active inhibitory component (Lavie & Cox, 1997; Lavie & Fox, 2000). In nonsearch tasks, facilitation from response-compatible flankers generally requires preexposure of the flankers, and the facilitation effect builds up as the flankers precede the target by 100-300 ms (Flowers, 1990; Taylor, 1977). Further research on this type of facilitation in search tasks would thus be informative.

An age-related slowing in overall rate of search, as reflected in the Age Group × Display Size interaction in the RT data and age-related increase in the RT × Display Size slopes, corresponded to the results of Experiment 1. The limitation on display duration in Experiment 2, however, did not lead to an age difference in the pattern of compatibility effects. The search times of both age groups were increased by distracting information at the smaller perceptual loads, but not at the largest perceptual load, suggesting that younger adults and older adults were similarly able to avoid disruption from the distractors as perceptual load increased. The magnitude of the RT compatibility effects did not differ as a function of age group at any of the display sizes. This pattern of results argues against both of the age effects proposed by Maylor and Lavie (1998): (a) an age-related deficit in the ability to inhibit distracting information at the lower perceptual loads and (b) an age-related decline in processing capacity as reflected in the change in distraction as a function of increasing perceptual load.

The effects of display size and compatibility in the error rate data were consistent with those observed for RT (i.e., conditions leading to higher RT also generally led to higher error rates). An Age Group × Compatibility interaction was observed in the error data, suggesting that the older adults' performance was differentially affected by response-compatible distractors, but this effect did not interact with perceptual load.

Experiment 3

The question remains as to what variables accounted for the different pattern of age effects in Experiments 1 and 2 as compared with the case in Maylor and Lavie (1998). It is important to note that participants in the Maylor and Lavie experiments, particularly the older adults, exhibited higher error rates than we obtained in Experiments 1 and 2, probably as a result of the very brief (100 ms) display duration used by Maylor and Lavie. It is possible that the critical variable for age differences in distraction is not limited display duration per se, but a duration that is sufficiently limited to lead to a high error rate. As discussed in the introduction to this article, another possible source of age differences in the present type of task is the use of a peripheral distractor that functions as an onset singleton (Juola et al., 2000;Pratt & Bellomo, 1999). By incorporating the distractor into the display, we may have eliminated this source of age-related increase in distraction. Also note that the overall processing load associated with the search task may have been greater in the present study than in the Maylor and Lavie study. We assigned two targets to each response, whereas Maylor and Lavie assigned one target. We presented two distractors in the display, whereas Maylor and Lavie presented one.

In view of the discrepant findings, we decided it would be most useful to attempt to replicate the results of Maylor and Lavie (1998). Toward this end, we used the same stimuli, visual display layout, display duration, and sequence of trials as in Experiment 1 of Maylor and Lavie[1]. This effectively led to the following changes from the first two experiments: we (a) limited the display duration to 100 ms; (b) moved the distractor outside the display; (c) presented one distractor per display; (d) varied the location of the distractor to the left and right of the circular display; (e) used two possible target letters, with one target letter assigned to each response; (f) used only incompatible and neutral distractors; (g) included relevant display sizes of one, two, four, and six items; (h) reduced the diameter of the display; and (i) increased the size of the distractor relative to the display items. We sought to determine whether these changes would result in age-related increases in both the magnitude of interference at smaller perceptual loads and the rate of resolution of compatibility effects with increasing perceptual load.

Method

Participants—Twenty-four younger adults between 18 and 29 years of age and 24 older adults between 60 and 80 years of age participated in Experiment 3 (Table 1). There were 12 women in each age group. Participants were recruited in the same manner as in Experiments 1 and 2, but none had participated in the previous experiments. One older adult was replaced because of mean response times that were more than three standard deviations away from the group mean, and three older adults were replaced because of corrected acuity scores that were worse than 20/40.

Apparatus and stimuli—Participants completed the task in the same testing environment and on the same equipment as in Experiments 1 and 2. The stimuli were light gray characters presented against a black background. Each trial contained a display with one target letter and zero, one, three, or five nontarget letters, plus one distractor letter placed peripherally to the display (Figure 4). Target and nontarget letters were arranged around the perimeter of an imaginary circle with six positions. The diameter of the circle subtended a visual angle of 4.2° at a viewing distance of 60 cm. Letters in the circle were presented in an uppercase sans serif font subtending visual angles of 0.6° vertically and 0.4° horizontally. Depending on letter shape, the distance between adjacent letters in the six-item displays was 1.4°-1.91°. The

---

[1] We are grateful to Elizabeth Maylor and Nilli Lavie for providing us with the computer program that they used in Experiment 1 of their study.

peripheral distractor appeared equally often to the left or to the right of the circular display at a horizontal distance of 4.3° from fixation and subtending a visual angle of 0.9° vertically and 0.5° horizontally. The distractor letter was larger than both the target and nontarget letters to compensate for the reduced acuity accompanying the greater distance from fixation.

The two target letters were *X* and *N*, assigned to separate response keys. The distractor letters were *X*, *N*, *T*, and *L*. Two compatibility conditions (incompatible and neutral) defined the relationship between the target and the distractor. The distractor letter of the incompatible condition was the letter assigned to the opposite response of the target (e.g., if the target letter was *N*, the distractor letter was *X*). For neutral trials, the distractor letter was one of two letters not associated with a response (*T* or *L*). The possible identities of the remaining letters in the display, the nontarget letters, were *Z*, *K*, *H*, *Y*, and *V*. The positions of the targets and nontargets were counterbalanced for each of the display sizes.

Procedure—The experimenter explained the task to participants with the assistance of drawn examples of the display configurations. Participants were told that one of the two target letters would appear on every trial in one of the positions of the circular display. When an *X* was presented, they should press the “0” key on the numeric keypad of the keyboard with their right thumb, and when an *N* was presented, they should press the “2” key with their right index finger. They were further instructed to ignore the letter presented outside the circular display, even if a target letter was presented there. Participants were encouraged to perform the task quickly while maintaining high accuracy.

A trial proceeded as follows: A fixation point (a small dot) appeared in the center of the screen for 1 s, followed by the circular letter display for 100 ms, and then by a blank screen. Reaction time was measured from the onset of the circular display. An incorrect response or a failure to respond within 4 s of the onset of the display triggered error feedback in the form of a brief computer tone. Responses were followed by an interval of 1 s before presentation of the fixation point for the next trial.

Participants completed two practice blocks, each containing 12 trials. To acquaint participants with the task, the circular displays in the first block were presented until the participant responded. The second practice block presented the circular displays for the same duration (100 ms) as the test trials. After the practice blocks, participants completed 10 blocks of 96 trials. The four display sizes were intermixed at random and presented with equal probability in each block. The first block was treated as practice and was not included in the data analysis. Participants were allowed to rest between blocks of trials; they pressed the space bar of the keyboard when ready to proceed with a block. Because of the brief presentation of the display, eye movements were not monitored.

Results

Reaction time—Individual trials for which RT was less than 150 ms or more than 3,000 ms were considered outliers and were eliminated. This criterion eliminated less than 1% of trials for both age groups, and the mean percentage of outliers did not exceed 4% for an individual participant.

The means of median RTs for correct responses are presented in Table 4. A 2 × 2 × 4 mixed ANOVA was conducted with age group (younger adults and older adults) as the between-subjects variable and compatibility condition (incompatible and neutral) and display size (one, two, four, and six items) as the within-subjects variables. Main effects were found for all three variables: age group, $F(1, 46) = 61.2$, $p < .01$; compatibility condition, $F(1, 46) = 88.6$, $p < .01$; and display size, $F(3, 138) = 317.5$, $p < .01$. Older adults were 223 ms slower than were younger adults; incompatible RTs were 49 ms higher than were neutral RTs; and search RTs increased by 68 ms from Display Size 1 to Display Size 2, by 76 ms from Display Size 2 to Display Size 4, and by 69 ms from Display Size 4 to Display Size 6.

All three two-way interactions were significant: Age Group × Display Size, $F(3, 138) = 13.7$, $p < .01$; Age Group × Compatibility, $F(1, 46) = 9.2$, $p < .01$; and Compatibility × Display Size, $F(3, 138) = 7.4$, $p < .01$. The RT increase with display size was greater for older adults (mean RT slope = 49 ms per item, mean $r^2 = .89$) than for younger adults (mean RT slope = 34 ms per item, mean $r^2 = .97$); compatibility effects (incompatible RT-neutral RT) were greater for older adults (64 ms) than for younger adults (33 ms); and compatibility effects were significantly smaller at Display Size 6 (19 ms) than at Display Sizes 1, 2, or 4 (55, 61, and 59 ms, respectively). In contrast to the case in the first two experiments, these two-way interactions were qualified by a three-way interaction of Age Group × Compatibility × Display Size, $F(3, 138) = 3.6$, $p < .02$.

To explore the three-way interaction, we conducted Compatibility × Display Size ANOVAs within each age group. There were significant main effects of compatibility condition and display size for each age group ($p < .01$) in each case. The Compatibility × Display Size interaction, reflecting perceptual load effects, was significant only for the older adults, $F(3, 69) = 6.5$, $p < .01$. Considering the older adults separately, their incompatible RTs were slower than their neutral RTs at Display Sizes 1, 2, and 4, $F(1, 23) > 28.0$, $p < .01$, in each case, but not at Display Size 6 ($F < 1.0$). Paired comparison of the difference scores reflecting compatibility effects (incompatible RT-Neutral RT; Figure 5) demonstrated that for the older adults, the compatibility effects at Display Sizes 1, 2, and 4 did not differ in magnitude; all of these values were greater than the compatibility effect at Display Size 6. The older adults had significantly higher compatibility effects than younger adults at each of the three lower display sizes, $F(1, 46) > 5.9$, $p < .02$, in each case, but not at Display Size 6 ($F < 1.0$).

Following the approach of Maylor and Lavie (1998), we also analyzed the RT data by a proportional transformation to take into account the effects of generalized age-related slowing. For each participant and task condition, the incompatible RT-neutral RT compatibility effect was divided by neutral RT (Figure 6). The proportion scores were submitted to the same Age Group × Display Size ANOVA as the absolute difference scores. The patterns found with the transformed data largely replicated the findings with the untransformed scores. The ANOVA yielded main effects of age group, $F(1, 46) = 4.2$, $p < .05$, and display size, $F(3, 138) = 12.3$, $p < .01$, as well as an Age Group × Display Size interaction, $F(3, 138) = 2.8$, $p < .05$, that corresponded to the three-way interaction in the untransformed data.

For older adults, the change in the compatibility effect as a function of display size, $F(3, 69) = 9.5$, $p < .01$, was similar to the untransformed data, with higher proportional difference scores at Display Sizes 1, 2, and 4 than at Display Size 6. In contrast to the difference score analysis, younger adults' compatibility effects were found to differ across the four display sizes, $F(3, 69) = 3.2$, $p < .05$. Younger adults' compatibility effects were significantly greater at Display Size 1 than at Display Size 6, but Display Sizes 2 and 4 were not distinguishable from the other display sizes by pairwise comparison. In the proportional difference score analysis, the older adults' compatibility effects were higher than those of the younger adults at Display Size 1, $F(1, 46) = 4.8$, $p < .05$, and at Display Size 2, $F(1, 46) = 8.2$, $p < .01$, but not at the other display sizes.

Errors—The mean rate of response failures was less than 1% of trials for each age group. The error rates (Table 4) were somewhat higher than those of the previous experiments and were submitted to an ANOVA using the same variables as the RT analysis. Main effects were significant for age group, $F(1, 46) = 53.9$, $p < .01$; compatibility condition, $F(1, 46) = 38.3$, $p < .01$; and display size, $F(3, 138) = 189.4$, $p < .01$. Older adults made more errors (15.1%)

than did younger adults (5.0%); incompatible errors (11.2%) were greater than neutral errors (9.0%); and error rates increased from 3.7% at Display Size 1 to 5.5% at Display Size 2, 11.9% at Display Size 4, and 19.3% at Display Size 6.

All three two-way interactions were significant: Age Group × Compatibility, $F(1, 46) = 14.5$, $p < .01$; Age Group × Display Size, $F(3, 138) = 25.9$, $p < .01$; and Compatibility × Display Size, $F(3, 138) = 3.5$, $p < .02$. These interactions were qualified by the three-way interaction of Age Group × Compatibility × Display Size, $F(3, 138) = 3.2$, $p < .05$.

We examined the three-way interaction by conducting Compatibility × Display Size ANOVAs within each age group. There were significant main effects of compatibility condition and display size within the age groups ($p < .02$) in each case, but the interaction of compatibility condition and display size, reflecting perceptual load effects, was significant only for the older adults, $F(3, 138) = 4.1$, $p < .05$. For older adults, incompatible errors were greater than neutral errors at the three lower display sizes, $F(1, 23) > 12.0$, $p < .01$, in each case, but not at Display Size 6 ($F < 1.0$). Pairwise comparison of the error rate difference scores (incompatible errors-neutral errors) indicated that for older adults, the only significant difference was between Display Size 4 (5.9%) and Display Size 6 (1.0%). The error rate effects were greater for the older adults than for the younger adults at each of the three lower display sizes, $F(1, 46) > 5.8$, $p < .05$, in each case, but not at Display Size 6 ($F < 1.0$).

Discussion

Among the several methodological changes that we made in Experiment 3 in our attempt to reinstate the viewing conditions of Maylor and Lavie (1998), two are particularly important. First, we presented the visual displays for a very brief duration (100 ms). With this change, error rates increased compared with those in the first two experiments, particularly for older adults at the larger display sizes (27% at Display Size 6). This error rate is comparable to that reported by Maylor and Lavie and reflects a more datalimited level of performance than do Experiments 1 and 2. A second important modification to the visual search task in Experiment 3 was the displacement of the distractor letter to a location outside the circular display of relevant letters. This relocation caused the distractor to become a visual singleton. We anticipated that both the shortened display duration and the distractor’s status as a singleton would lead to age-related increases in selection difficulty (Harpur et al., 1995;Juola et al., 2000;Pratt & Bellomo, 1999).

The overall pattern of RT distraction effects was consistent with that of Experiments 1 and 2, and with the results of Maylor and Lavie (1998), in that the influence of the response-incompatible distractor decreased as a function of increasing display size (i.e., the perceptual load effect). We also replicated the age-related slowing in the rate of search, as expressed in the age-related increase in the slope of the linear RT × Display Size functions. Significantly, in the RT data for Experiment 3, we also found that age group interacted with perceptual load in a manner corresponding to the results of Maylor and Lavie. In the analysis of the untransformed RT data, there was a significant Age Group × Compatibility × Display Size interaction, as a result of a more pronounced perceptual load effect for older adults than for younger adults. This pattern was confirmed by the Age Group × Display Size interaction in the analysis of the proportional RT difference scores for the compatibility effects. Consistent with the perceptual load theory, the compatibility effects were greater for older adults than for younger adults at the lower perceptual loads. In neither of the analyses was the age difference significant for Display Size 6.

Given the finding of age differences in distraction in this experiment but not in the earlier two experiments, it seems likely that either the limited duration of the display or the singleton status of the distractor, or both, disproportionately affected the selection abilities of older adults compared with those of younger adults. Because these variables were not manipulated independently, however, the specific reason for the appearance of age differences in Experiment 3 cannot be determined.

The error data were consistent with the RT data, and the display size and compatibility conditions leading to higher RTs generally led to higher error rates as well. As in the RT data, the change in the error rate compatibility effects as a function of increasing perceptual load was more prominent in the older adults' error rates than in those of the younger adults.

The pattern of age effects in relation to perceptual load differed in some respects, however, from that observed by Maylor and Lavie (1998). These authors found that the compatibility effect was greater for older adults than for younger adults only at the lowest level of load (Display Size 1), whereas we obtained a significant age-related increase in the compatibility effect at Display Sizes 1, 2, and 4, both in the untransformed RT data and the error rate data, and at Display Sizes 1 and 2 in the proportional RT difference scores. Thus, in our data we find a somewhat more pronounced age-related decline in selective attention than reported previously.

In addition, Maylor and Lavie (1998) reported that the compatibility effects declined significantly from Display Size 1 to Display Size 4 for older adults, whereas compatibility effects did not diminish before Display Size 6 for younger adults. Maylor and Lavie interpreted this pattern as consistent with an age-related reduction in attentional capacity, which led to improved selection for older adults with smaller increases in perceptual load. We found, in contrast, that compatibility effects did not diminish in either group before Display Size 6. It consequently appears that the attentional capacity demands of this task, as defined by the change in the compatibility effect at a particular increment of display size, did not vary as a function of age group. Although the Age Group × Compatibility × Display Size interaction was significant, this interaction was driven by the magnitude of the age difference at the lower perceptual loads, rather than by a change in the point (on the display size function) at which selectivity became more efficient.

General Discussion

In the present three visual search experiments, we investigated whether Maylor and Lavie's (1998) findings of age differences in visual selective attention could be replicated under higher accuracy, resource-limited conditions. As is evident in Figures 2,3,5, and 6, perceptual load and selective attention generally interacted in the manner predicted by Lavie's (1995) theory, in all three experiments. The disruption from distractors, as measured by the effects of compatibility on RT, diminished as display size increased. That is, selective attention became more efficient as the perceptual load increased. We were thus able to replicate perceptual load effects under resource-limited conditions and without presenting the distractor as a singleton outside the display.

In addition, the results of Experiments 1 and 2 suggest that the disruptive influence of distraction is not due entirely to response competition but instead reflects more general inhibitory function, relating to the internal recognition responses to display items (C. W. Eriksen & Schultz, 1979; Grice & Gwynne, 1985; Proctor & Fober, 1985). The evidence for this general inhibitory process is that at the lower perceptual loads of Experiments 1 and 2 (Display Sizes 2 and 4), both compatible and incompatible RTs were higher than neutral RT. There was also a further, specific effect of response competition, in terms of an increase in RT for incompatible trials relative to compatible trials at Display Size 4, in both Experiments 1 and 2. It is not clear, however, why the response competition effect was associated only with Display Size 4 (and not Display Size 2) in both Experiments 1 and 2, and supplementary analyses conducted on target-distractor distance did not yield a consistent contribution of the distance variable.

There was an intriguing, though nonsignificant, effect of facilitation for compatible trials, in the range of 27-28 ms, at Display Size 6 in both Experiments 1 and 2, which raises the possibility that an automatic influence of the distractors is present even when attentional capacity limits are exceeded. This possibility, which would appear to be easily incorporated into the perceptual load theory, could be investigated further by examining conditions (e.g., preexposure of the distractors) that maximize the facilitative contribution of response-compatible nontargets (Flowers, 1990; Taylor, 1977).

Both Experiments 1 and 2 demonstrated an age-related decline in the overall efficiency of search, as reflected in the age-related increase in the slopes relating RT to display size. This type of age-related change has been observed frequently under resource-limited conditions and can be accounted for by general (relatively task-independent) changes in the speed of visual information processing (Madden, 2001; Madden et al., 1996; Plude & Hoyer, 1986). It is also interesting to note that the degree of age-related slowing, in terms of the ratio of older adults' RT slopes to those of the younger adults, decreased markedly from Experiment 1 (1.71) to Experiment 2 (1.25). The only difference between these experiments was the duration of the display, which was unlimited in Experiment 1 and limited in Experiment 2 (250 ms for younger adults; 750 ms for older adults). The change in the magnitude of the age difference suggests that in addition to generalized slowing, age-related changes in RT measures of search performance may reflect an increase in cautiousness, or a decision-checking procedure, that is short-circuited by limiting the display duration (cf. Zacks & Zacks, 1993).

Although distraction decreased with perceptual load in Experiments 1 and 2, it did not vary as a function of age group. At the lower perceptual loads, irrelevant information disrupted the search performance of younger and older adults to a comparable degree. Thus, under the viewing conditions of Experiments 1 and 2, there was little support for the Maylor and Lavie (1998) proposal of an age-related decline in selective attention. The only interaction involving age group in Experiments 1 and 2 was the age-related increase in error rate for the compatible trials in Experiment 2. These results are consistent with previous experiments reporting age similarities in response compatibility effects and related measures of inhibition (Hahn & Kramer, 1995;Kramer et al., 1994;Langley, Overmier, Knopman, & Prod' Homme, 1998). When, however, in Experiment 3 we reinstated the more data-limited conditions of Maylor and Lavie, we obtained an age-related change in the perceptual load effect that resembled their findings. Experiment 3 yielded an Age Group × Compatibility × Display Size interaction for both RT and error rate that was consistent with the pattern observed by Maylor and Lavie. In this experiment, search performance for older adults was disproportionately affected by distraction at the lower levels of perceptual load, suggesting an age-related decline in selective attention.

The most substantial of the design changes in Experiment 3 involved limiting the display duration to 100 ms for both age groups and presenting an individual distractor that was peripheral to the display. These changes led to an increase in the error rate relative to Experiments 1 and 2, particularly for Display Size 6. It thus appears that although the perceptual load effect is reliable under resource-limited conditions, either restricting display duration to a more data-limited level, using an external singleton distractor, or both variables combined is largely responsible for age-related changes in the interaction between selective attention and perceptual load. These results are in accord with other findings indicating that age-related changes related to selective attention become more pronounced at briefer display durations (Harpur et al., 1995; Scialfa & Harpur, 1994) and in the presence of onset singletons (Juola et al., 2000; Pratt & Bellomo, 1999). More generally, these findings suggest that some estimates of age-related declines in selective attention and inhibition may be dependent on task performance that is driven by local stimulus features (i.e., bottom-up processing). It will thus be useful in future studies to compare directly the efficiency of bottom-up and top-down (cognitive) attentional control for younger and older adults (Folk & Lincourt, 1996; Humphrey & Kramer, 1997).

In the context of the viewing conditions used in Experiment 3, the age-related increase in the compatibility effect at the lower levels of perceptual load supports the hypothesis of an age-related decline in selective attention as proposed by Maylor and Lavie (1998). Our data are less persuasive, however, that this decline is attributable to attentional capacity limitations as defined by the perceptual load theory. According to Maylor and Lavie, age differences in capacity limitations are reflected in the fact that a significant decrease in the magnitude of the compatibility effect occurred by an earlier point on the perceptual load function for older adults (Display Size 4) than for younger adults (Display Size 6). Neither age group in Experiment 3, however, exhibited a significant decline in the compatibility effect at a lower level of perceptual load than Display Size 6. Age-related slowing as defined by the slope of the RT × Display Size function remained significant in Experiment 3, as in Experiments 1 and 2. The age-related change in selective attention appears to be separable from generalized slowing, in that the age differences in mean RT were most pronounced at the higher levels of perceptual load, whereas the age differences in the compatibility effects were most pronounced at the lower levels of load. But the pattern of age differences in the compatibility effects was not readily attributable to age-related changes in attentional capacity.

Conclusion

Experiments 1 and 2 demonstrated that the perceptual load effect, representing increasing efficiency of selective attention as a function of increasing perceptual load, is reliable in the context of a resource-limited search task with nonsingleton distractors. At the lower perceptual loads, the disruption of search performance from irrelevant distractors reflected different forms of inhibitory mechanisms: both a general effect related to internal recognition responses and a more specific effect related to response competition. Under resource-limited conditions, however, there was no age-related change in the perceptual load effect, although the overall efficiency of search was lower for older adults than for younger adults. In the context of a more data-limited search task with a singleton distractor (Experiment 3), there was an age-related decline in selective attention, but little evidence that would link this age difference to attentional capacity limitations. In further investigations it will be useful to determine the relative contributions of bottom-up and top-down attentional processing to age differences in visual selective attention.

References

Anderson ND. The attentional demands of encoding and retrieval in younger and older adults: 2. Evidence from secondary task reaction time distributions. Psychology and Aging 1999;14:645–655. [PubMed: 10632151]

Bacon WF, Egeth HE. Overriding stimulus-driven attentional capture. Perception & Psychophysics 1994;55:485–496. [PubMed: 8008550]

Burke DM. Language, aging, and inhibitory deficits: Evaluation of a theory. Journal of Gerontology: Psychological Sciences 1997;52B:P254–P264.

Cerella J. Age-related decline in extrafoveal letter perception. Journal of Gerontology 1985;40:727–736. [PubMed: 4056329]

Craik, FIM.; Byrd, M. Aging and cognitive deficits: The role of attentional resources. In: Craik, FIM.; Trehub, S., editors. Aging and cognitive processes. Plenum; New York: 1982. p. 191-211.

Eriksen BA, Eriksen CW. Effects of noise letters upon the identification of a target letter in a nonsearch task. Perception & Psychophysics 1974;16:143–149.

Eriksen CW. The flankers task and response competition: A useful tool for investigating a variety of cognitive problems. Visual Cognition 1995;2:101–118.

Eriksen CW, Schultz DW. Information processing and visual search: A continuous flow conception and experimental results. Perception & Psychophysics 1979;25:249–263. [PubMed: 461085]

Eriksen CW, Yeh Y-Y. Allocation of attention in the visual field. Journal of Experimental Psychology: Human Perception and Performance 1985;11:583–597. [PubMed: 2932532]

Folk CL, Lincourt AE. The effects of age on guided conjunction search. Experimental Aging Research 1996;22:99–118. [PubMed: 8665990]

Flowers JH. Priming effects in perceptual classification. Perception & Psychophysics 1990;47:135–148. [PubMed: 2304812]

Grice GR, Gwynne JW. Temporal characteristics of noise conditions producing facilitation and interference. Perception & Psychophysics 1985;37:495–501. [PubMed: 4059004]

Hahn S, Kramer AF. Attentional flexibility and aging: You don't need to be 20 years of age to split the beam. Psychology and Aging 1995;10:597–609. [PubMed: 8749587]

Handy TC, Mangun GR. Attention and spatial selection: Electrophysiological evidence for modulation by perceptual load. Perception & Psychophysics 2000;62:175–186. [PubMed: 10703265]

Harpur LL, Scialfa CT, Thomas DM. Age differences in feature search as a function of exposure duration. Experimental Aging Research 1995;21:1–15. [PubMed: 7744167]

Hartley, AA. Attention. In: Craik, FIM.; Salthouse, TA., editors. The handbook of aging and cognition. Erlbaum; Hillsdale, NJ: 1992. p. 3-50.

Hasher, L.; Zacks, RT.; May, CP. Inhibitory control, circadian arousal, and age. In: Gopher, D.; Koriat, A., editors. Attention and performance XVII: Cognitive regulation of performance: Interaction of theory and application. MIT Press; Cambridge, MA: 1999. p. 653-675.

Humphrey DG, Kramer AF. Age differences in visual search for feature, conjunction, and triple-conjunction targets. Psychology and Aging 1997;12:704–717. [PubMed: 9416638]

Juola JF, Koshino H, Warner CB, McMickell M, Peterson M. Automatic and voluntary control of attention in young and older adults. American Journal of Psychology 2000;113:159–178. [PubMed: 10862340]

Kane MJ, Hasher L, Stoltzfus ER, Zacks RT, Connelly SL. Inhibitory attentional mechanisms and aging. Psychology and Aging 1994;9:103–112. [PubMed: 8185857]

Kramer AF, Humphrey DG, Larish JF, Logan GD, Strayer DL. Aging and inhibition: Beyond a unitary view of inhibitory processing in attention. Psychology and Aging 1994;9:491–512. [PubMed: 7893421]

Langley LK, Overmier JB, Knopman DS, Prod'Homme MM. Inhibition and habituation: Preserved mechanisms of attentional selection in aging and Alzheimer's disease. Neuropsychology 1998;12:353–366. [PubMed: 9673993]

Lavie N. Perceptual load as a necessary condition for selective attention. Journal of Experimental Psychology: Human Perception and Performance 1995;21:451–468. [PubMed: 7790827]

Lavie N, Cox S. On the efficiency of visual selective attention: Efficient visual search leads to inefficient distractor rejection. Psychological Science 1997;8:395–398.

Lavie N, Fox E. The role of perceptual load in negative priming. Journal of Experimental Psychology: Human Perception and Performance 2000;26:1038–1052. [PubMed: 10884008]

Lavie N, Tsal Y. Perceptual load as a major determinant of the locus of selection in visual attention. Perception & Psychophysics 1994;56:183–197. [PubMed: 7971119]

Madden DJ. Selective attention and visual search: Revision of an allocation model and application to age differences. Journal of Experimental Psychology: Human Perception and Performance 1992;18:821–836. [PubMed: 1500878]

Madden, DJ. Speed and timing of behavioral processes. In: Birren, JE.; Schaie, KW., editors. Handbook of the psychology of aging. 5th ed.. Academic Press; San Diego, CA: 2001. p. 288-312.

Madden DJ, Gottlob LR. Adult age differences in strategic and dynamic components of focusing visual attention. Aging, Neuropsychology, and Cognition 1997;4:185–210.

Madden DJ, Pierce TW, Allen PA. Adult age differences in the use of distractor homogeneity during visual search. Psychology and Aging 1996;11:454–474. [PubMed: 8893315]

Madden, DJ.; Plude, DJ. Selective preservation of selective attention. In: Cerella, J.; Rybash, J.; Hoyer, W.; Commons, ML., editors. Adult information processing: Limits on loss. Academic Press; San Diego, CA: 1993. p. 273-300.

Maylor EA, Lavie N. The influence of perceptual load on age differences in selective attention. Psychology and Aging 1998;13:563–573. [PubMed: 9883457]

McDowd, JM.; Shaw, RJ. Attention and aging: A functional perspective. In: Craik, FIM.; Salthouse, TA., editors. The handbook of aging and cognition. 2nd ed.. Erlbaum; Mahwah, NJ: 2000. p. 221-292.

Plude DJ, Hoyer WJ. Age and the selectivity of visual information processing. Psychology and Aging 1986;1:4–10. [PubMed: 3267377]

Posner, MI.; Snyder, CRR. Facilitation and inhibition in the processing of signals. In: Rabbitt, PMA.; Dornic, S., editors. Attention and performance V. Academic Press; New York: 1975. p. 669-682.

Pratt J, Bellomo CN. Attentional capture in younger and older adults. Aging, Neuropsychology, and Cognition 1999;6:19–31.

Proctor RW, Fober GW. Repeated-stimulus superiority and inferiority effects in the identification of letters and digits. Perception & Psychophysics 1985;38:125–134. [PubMed: 4088804]

Rees G, Frith CD, Lavie N. Modulating irrelevant motion perception by varying attentional load in an unrelated task. Science 1997;278:1616–1619. [PubMed: 9374459]

Salthouse TA. What do adult age differences in the digit symbol substitution test reflect? Journal of Gerontology: Psychological Sciences 1992;47:P121–P128.

Salthouse TA. The processing-speed theory of adult age differences in cognition. Psychological Review 1996;103:403–428. [PubMed: 8759042]

Santee JL, Egeth HE. Do reaction time and accuracy measure the same aspects of letter recognition? Journal of Experimental Psychology: Human Perception and Performance 1982;8:489–501. [PubMed: 6214603]

Schneider W. Micro Experimental Laboratory: An integrated system for IBM PC compatibles. Behavior Research Methods, Instruments, and Computers 1988;20:206–217.

Scialfa CT, Harpur LL. Effects of similarity and duration on age differences in visual search. Canadian Journal on Aging 1994;13:51–65.

Sullivan MP. The functional interaction of visual-perceptual and response mechanisms during selective attention in young adults, young-old adults, and old-old adults. Perception and Psychophysics 1999;61:810–825. [PubMed: 10498997]

Taylor DA. Time course of context effects. Journal of Experimental Psychology: General 1977;106:404–426.

Theeuwes J, Burger R. Attentional control during visual search: The effect of irrelevant singletons. Journal of Experimental Psychology: Human Perception and Performance 1998;24:1342–1353. [PubMed: 9778827]

Wechsler, D. Wechsler Adult Intelligence Scale—Revised. Psychological Corporation; New York: 1981.

Wolfe, JM. Visual search. In: Pashler, H., editor. Attention. Psychology Press; East Sussex, UK: 1998. p. 13-73.

Wright LL, Elias JW. Age differences in the effects of perceptual noise. Journal of Gerontology 1979;34:704–708. [PubMed: 469189]

Yantis S, Jones E. Mechanisms of attentional selection: Temporally modulated priority tags. Perception & Psychophysics 1991;50:166–178. [PubMed: 1945738]

Zacks JL, Zacks RT. Visual search times assessed without reaction times: A new method and an application to aging. Journal of Experimental Psychology: Human Perception and Performance 1993;4:798–813. [PubMed: 8409859]

Zeef EJ, Kok A. Age-related differences in the timing of stimulus and response processes during visual selective attention: Performance and psychophysiological analysis. Psychophysiology 1993;30:138–151. [PubMed: 8434077]

Zeef EJ, Sonke CJ, Kok A, Buiten MM, Kenemans JL. Perceptual factors affecting age-related differences in focused attention: Performance and psychophysiological analysis. Psychophysiology 1996;33:555–565. [PubMed: 8854743]

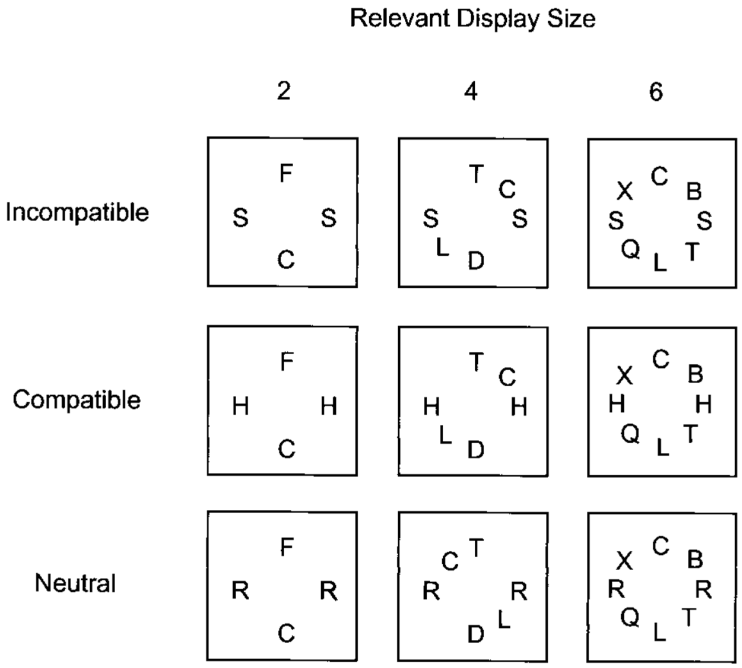

Figure 1.
Examples of the displays (no. of letters) used in Experiments 1 and 2. The participant's task was to identify which of four target letters (*H*, *C*, *S*, or *K*) was present in the display. The letters *H* and *C* were assigned to one response, and the letters *S* and *K* were assigned to the other response. Target location varied from trial to trial. Participants were instructed to ignore the distractor locations (3 and 9 o'clock), even if a target letter was presented there. In each of the sample displays, the target letter is *C*, but the distractor letter varies by condition. In the incompatible condition, the distractor letter was one of the letters assigned to the opposite response of the target letter (e.g., the target was *C*, the distractor was *S* or *K*). In the compatible condition, the distractor letter was assigned to the same response as the target letter (e.g., the target was *C*, the distractor was *H*). In the neutral condition, the distractor was a letter not assigned to a response (the letter *R*). In the experiments, the displays were presented as white letters against a black background. The sample displays are not scaled to size.

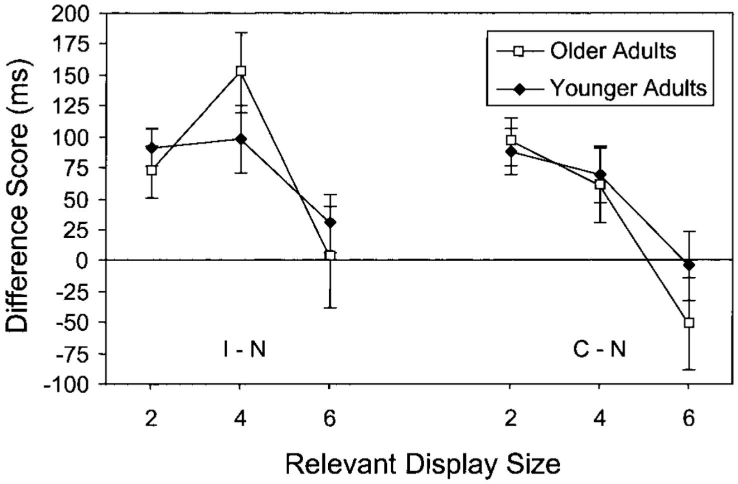

Figure 2.

Mean reaction time difference scores (with standard error bars) representing compatibility effects for younger and older adults as a function of relevant display size (no. of letters) for Experiment 1. I-N = incompatible RT minus neutral RT; C-N = compatible RT minus neutral RT.

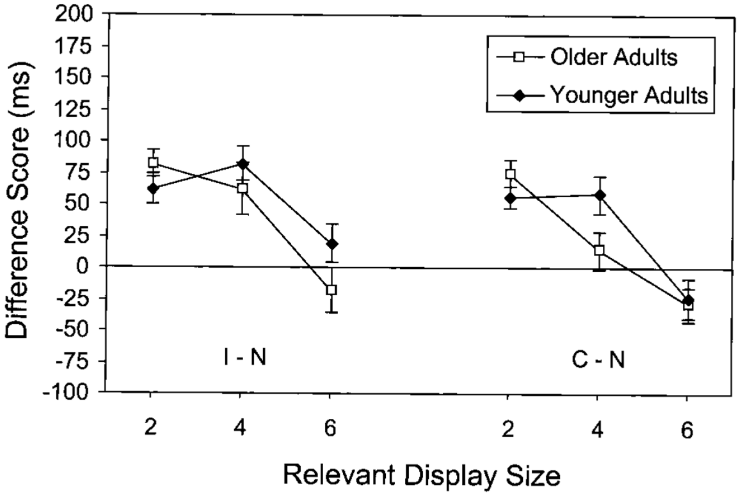

Figure 3.

Mean reaction time difference scores (with standard error bars) representing compatibility effects for younger and older adults as a function of relevant display size (no. of letters) for Experiment 2. I-N = incompatible RT minus neutral RT; C-N = compatible RT minus neutral RT.

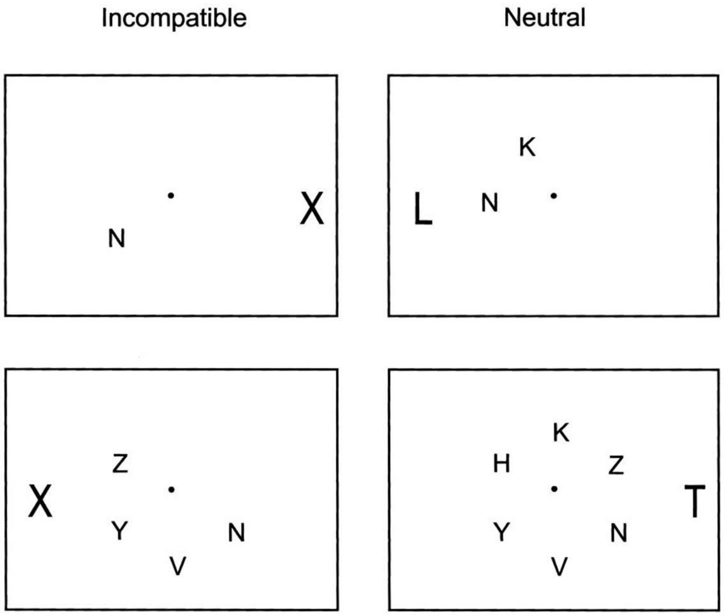

Figure 4.
Examples of the displays used in Experiment 3. The participant's task was to identify which of two target letters (*X* or *N*) was present in the display. Target location varied across the display positions. The distractor was always presented to the left or to the right of the display. Participants were instructed to ignore the letters presented outside the circle, even if a target letter was presented there. In each of the sample displays, the target letter is *N*, but the distractor letter varies by condition. In the incompatible condition, the distractor was the letter assigned to the opposite response of the target letter (e.g., the target was *N*, the distractor was *X*). In the neutral condition, the distractor was a letter not assigned to a response (the letter *T* or *L*). In the experiments, the displays were presented as light gray letters against a black background. The sample displays are not scaled to size.

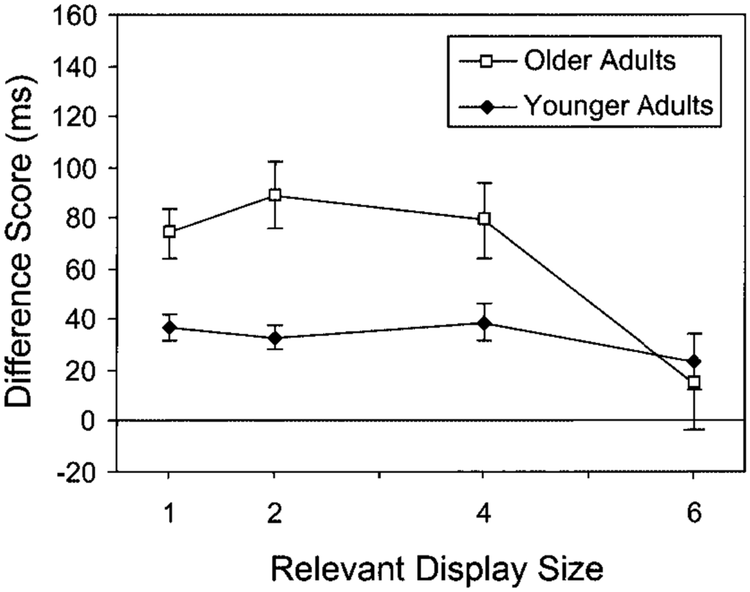

Figure 5.

Mean reaction time difference scores (with standard error bars) representing compatibility effects (incompatible RT-neutral RT) for younger and older adults as a function of relevant display size (no. of letters) in Experiment 3.

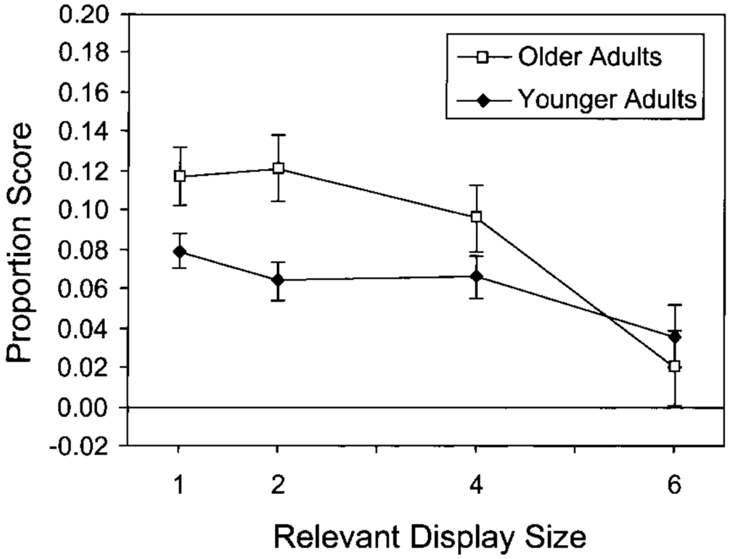

Figure 6.

Mean reaction time proportion scores (with standard error bars) representing compatibility effects [(incompatible RT-neutral RT)/neutral RT] for younger and older adults as a function of relevant display size (no. of letters) in Experiment 3.

Table 1

Participant Characteristics

Characteristic	M		SD		Range	
	Younger	Older	Younger	Older	Younger	Older
Experiment 1 (n = 24 per group)						
Age (years)	20	70[a]	2	5	18-24	60-81
Education (years)	13	16[a]	1	3	12-16	12-22
Acuity[b]	16	28[a]	2	10	15-20	15-40
Vocabulary (no. correct, max = 70)	62	62	5	5	51-70	52-69
Digit-Symbol accuracy (% correct)	97	95	3	6	86-100	73-100
Digit-Symbol RT (ms)	1,357	1,830[a]	243	294	1,009-1,969	1,273-2,557
Experiment 2 (n = 32 per group)						
Age (years)	20	68[a]	2	5	18-29	60-81
Education (years)	13	17[a]	1	3	12-16	12-22
Acuity[b]	16	26[a]	4	9	15-30	15-40
Vocabulary (no. correct, max = 70)	61	65[a]	5	3	53-69	57-70
Digit-Symbol accuracy (% correct)	96	97	3	4	89-100	84-100
Digit-Symbol RT (ms)	1,226	1,598[a]	176	202	917-1,620	1,216-2,025
Experiment 3 (n = 24 per group)						
Age (years)	20	66[a]	3	6	18-29	60-80
Education (years)	14	16[a]	2	2	12-18	12-22
Acuity[b]	15	21[a]	1	9	15-20	15-40
Vocabulary (no. correct, max = 70)	63	63	5	4	52-69	54-69
Digit-Symbol Accuracy (no. correct)	97	98	3	2	89-100	93-100
Digit-Symbol RT (ms)	1,200	1,830[a]	241	323	721-1,575	1,224-2,368

Note. max = maximum; RT reaction time.

[a] Age group comparison was significant at $p < .05$ by t test.

[b] Denominator of the Snellen fraction for corrected near vision.

Table 2

Mean Reaction Times (ms) and Error Rates (%) for Experiment 1

Variable	*M*, by display size[a]			*SD*, by display size[a]		
	2	**4**	**6**	**2**	**4**	**6**
Younger adults						
RT						
Incompatible	960	1,143	1,239	131	226	243
Compatible	958	1,115	1,204	164	197	224
Neutral	869	1,044	1,209	143	210	195
Errors						
Incompatible	1.6	3.9	2.9	1.9	4.3	2.4
Compatible	3.6	2.1	1.6	2.6	1.8	1.8
Neutral	1.6	1.8	3.0	1.9	2.3	3.1
Older adults						
RT						
Incompatible	1,239	1,590	1,736	241	363	406
Compatible	1,263	1,498	1,682	224	326	414
Neutral	1,167	1,438	1,733	258	301	360
Errors						
Incompatible	2.0	3.4	2.2	2.6	3.8	2.4
Compatible	3.5	2.4	1.3	2.9	2.4	1.6
Neutral	0.9	0.9	2.5	1.5	1.4	1.6

Note. RT reaction time.

[a] Display Sizes 2, 4, and 6 indicate two, four, and six relevant items in display, respectively.

Table 3

Mean Reaction Times (ms) and Error Rates (%) for Experiment 2

Variable	***M*, by display size**[a]			***SD*, by display size**[a]		
	2	**4**	**6**	**2**	**4**	**6**
Younger adults						
RT						
Incompatible	870	994	1,060	156	177	167
Compatible	863	970	1,017	158	182	165
Neutral	808	913	1,041	133	158	154
Errors						
Incompatible	2.1	6.4	10.6	2.5	4.7	5.7
Compatible	2.3	5.0	7.6	2.4	4.7	4.9
Neutral	1.5	3.4	8.7	2.0	3.0	5.6
Older adults						
RT						
Incompatible	1,027	1,185	1,236	158	189	178
Compatible	1,020	1,138	1,224	172	172	149
Neutral	945	1,123	1,253	164	178	165
Errors						
Incompatible	2.5	7.8	9.8	3.0	5.7	5.5
Compatible	3.4	7.2	10.4	2.7	5.3	5.1
Neutral	2.0	4.6	10.0	2.3	3.4	6.3

Note. RT reaction time.

[a] Display Sizes 2, 4, and 6 indicate two, four, and six relevant items in display, respectively.

Table 4

Mean Reaction Times (ms) and Error Rates (%) for Experiment 3

Parameter	*M*, by display size[a]				*SD*, by display size[a]			
	1	**2**	**4**	**6**	**1**	**2**	**4**	**6**
Younger adults								
RT								
Incompatible	525	564	629	692	80	80	89	103
Neutral	488	531	590	668	82	82	82	90
Errors								
Incompatible	1.9	2.2	5.5	12.2	1.7	1.6	5.1	7.7
Neutral	1.2	1.6	4.4	11.3	1.4	1.7	3.5	6.3
Older adults								
RT								
Incompatible	712	816	901	936	114	133	139	149
Neutral	638	727	822	921	100	101	113	141
Errors								
Incompatible	7.2	11.3	21.9	27.4	5.9	8.9	9.9	8.2
Neutral	4.5	6.7	16.0	26.4	3.9	5.5	8.6	6.9

Note. RT reaction time.

[a] Display Sizes 1, 2, 4, and 6 indicate one, two, four, and six relevant items in display, respectively.